Department of Transportation
Federal Aviation Administration
Aircraft Certification Service
Washington, D.C.

TSO-C146e

Effective
Date: 5/5/17

Technical Standard Order

Subject: Stand-Alone Airborne Navigation Equipment Using The Global Positioning System Augmented By The Satellite Based Augmentation System (SBAS)

1. PURPOSE. This technical standard order (TSO) is for manufacturers applying for a TSO authorization (TSOA) or letter of design approval (LODA). In it, we (the Federal Aviation Administration, (FAA)) tell you what minimum performance standards (MPS) your stand-alone airborne navigation sensors, using the global positioning system (GPS) augmented by the satellite based augmentation system (SBAS) must first meet for approval and identification with the applicable TSO marking.

2. APPLICABILITY. This TSO affects new applications submitted after its effective date.

a. TSO-C146d will also remain effective until November 5, 2018. After this date, we will no longer accept applications for TSO-C146d.

b. Stand-alone GPS/SBAS equipment approved under a previous TSOA may still be manufactured under the provisions of its original approval.

> **Note:** Applicants that used a TSO-C205 Delta-4 CCA will need to coordinate with their Delta-4 CCA supplier for documentation supporting TSO-C205a.

3. REQUIREMENTS. New models of stand-alone GPS/SBAS equipment identified and manufactured on or after the effective date of this TSO must meet the MPS qualification and documentation requirements for functional equipment Class Gamma or Class Delta-4 in RTCA, Inc. document RTCA/DO-229E, *Minimum Operational Performance Standards for Global Positioning System/Satellite-Based Augmentation System Airborne Equipment* dated December 15, 2016, Section 2. Class Gamma and Class Delta-4 equipment are defined in RTCA/DO-229E, Section 1.4. Appendix 2 adds a new section 1.8.3 and new leg type requirements in section 2.2.1.3.

> **Note:** Manufacturers have the option to use the RTCA/DO-229E changes described in Appendix 3. These changes are based on past commonly granted deviations.

a. An alternate method for applicants with a TSO-C146 revision ‘b’, ‘c’, or ‘d’ TSOA is to apply for TSO-C146e using their existing approved design data plus additional substantiation data showing compliance with the changes in RTCA/DO-229E. The four areas where requirements changed are: 1) expanding the SBAS pseudorandom noise (PRN) codes (i.e., PRN range of 120 thru 158); 2) ensuring a graceful degradation to GPS-only operations; 3) prohibiting use of the broadcast Navigation Message Correction Table; and, 4) for Class Gamma, adding the additional leg types described in appendix 2.

> **Note 1:** It is not necessary for applicants to re-submit previously approved deviations. Previously approved deviations, and any limitations, will apply to the TSO-C146e TSOA.

> **Note 2:** Applicants that used a TSO-C205 Delta CCA will need to coordinate with their Delta CCA supplier for documentation supporting TSO-C205a.

> **Note 3:** Applicants with Class 1 and 2, revision ‘b’ equipment must not have claimed the 3db broadband intra-system noise credit.

b. Class Delta-4 applicants have the option to use a TSO-C205a Delta-4 CCA functional sensor. Applicants choosing to use a TSO-C205a Delta-4 CCA can take certification compliance credit by virtue of the TSO-C205a TSOA for:

- Meeting the Class Delta-4 MPS requirements in section 2.1.1, 2.1.5, and 2.3;
- The hardware/software qualification;
- The failure condition classification; and,
- MPS section 2.5 performance testing (functional qualification) except those specified in Appendix 1 of this TSO.

c. The TSO-C146e, Class Delta-4 applicant using a TSO-C205a Delta CCA functional sensor shall perform the testing described in Appendix 1 and satisfy the remaining paragraphs in this TSO not covered by the bullets above to receive a TSO-C146e TSOA.

> **Note:** The end-use manufacturer that uses a TSO-C205a Delta CCA functional sensor as part of their TSO-C146e application assumes full responsibility for the design and

function under their TSO-C146e authorization per 14 CFR § 21 Subpart O, Technical Standard Order Approvals.

d. Functionality. This TSO's standards apply to equipment intended to accept a desired flight path and provide deviation commands keyed to that path. Pilots and autopilots will use these deviations to guide the aircraft. Except for automatic dependent surveillance with Class Gamma, these TSO standards do not address integration issues with other avionics.

e. Failure Condition Classifications.

(1) Misleading information for en route, terminal, approach lateral navigation (LNAV), and approach LNAV/vertical navigation (VNAV) navigation data is a *Major* failure condition,

(2) Failure of the function defined in paragraph **3.d** resulting in misleading information for approach localizer performance without vertical guidance (LP), and approach localizer performance with vertical guidance (LPV) navigation data is a *Hazardous* failure condition, and

(3) Loss of the function defined in paragraph **3.d** for en route through approach LP/LPV navigation data is a *Major* failure condition.

(4) Design the system to at least these failure condition classifications consistent with the operational capability.

f. Functional Qualification.

(1) Demonstrate the required functional performance under the test conditions specified in RTCA/DO-229E, Section 2.5, or

(2) When using a TSO-C205a Delta CCA functional sensor, demonstrate the required performance under the test conditions in appendix 1 of this TSO.

g. Environmental Qualification. Demonstrate the required performance under the test conditions specified in RTCA/DO-229E, Section 2.4 using standard environmental conditions and test procedures appropriate for airborne equipment. RTCA/DO-229E requires the use of RTCA/DO-160E, *Environmental Conditions and Test Procedures for Airborne Equipment*, dated December 9, 2004, Sections 4.0 through 8.0 and 10.0 through 25.0. You may use a different standard environmental condition and test procedure than RTCA/DO-160E, provided the standard is appropriate for the Stand-alone GPS/SBAS equipment.

Note 1: The use of RTCA/DO-160D (with Changes 1 and 2 only, incorporated) or earlier versions is generally not considered appropriate and will require substantiation via the deviation process as discussed in paragraph **3.g** of this TSO.

Note 2: Applicants using a TSO-C205a Delta-4 CCA must perform the environmental qualification with the Delta-4 CCA in the end-use equipment.

h. Software Qualification.

(1) If the article includes software, develop the software according to RTCA, Inc. document RTCA/DO-178C, *Software Considerations in Airborne Systems and Equipment Certification*, dated December 13, 2011, including referenced supplements as applicable, to at least the software level consistent with the failure condition classification defined in paragraph **3.b** of this TSO. You may also develop the software according to RTCA, Inc. document RTCA/DO-178B, dated December 1, 1992 if you follow the guidance in AC 20-115C (or later revision), *Airborne Software Assurance*.

(2) Applicants using a TSO-C205a Delta CCA functional sensor may use TSO-C205a as substantiation for the software qualification.

i. Electronic Hardware Qualification.

(1) If the article includes complex custom airborne electronic hardware, develop the component according to RTCA, Inc. Document RTCA/DO-254, *Design Assurance Guidance for Airborne Electronic Hardware*, to at least the design assurance level consistent with the failure condition classification defined in paragraph **3.b** of this TSO. For custom airborne electronic hardware determined to be simple, RTCA/DO-254, paragraph 1.6 applies.

Note: Applicants should refer to AC 20-152 (latest revision) for guidance on implementing RTCA/DO-254.

(2) Applicants using a TSO-C205a Delta CCA functional sensor may use TSO-C205a as substantiation for the hardware qualification.

j. Barometric-aided Fault Detection and Exclusion (FDE). If the equipment uses barometric-aiding to enhance FDE availability, then the equipment must meet the requirements in RTCA/DO-229E, appendix G.

k. Deviations. We have provisions for using alternate or equivalent means of compliance to the criteria in the MPS of this TSO. If you invoke these provisions, you must show that your equipment maintains an equivalent level of safety. Apply for a deviation under the provision of 14 CFR § 21.618.

4. MARKING.

a. Mark at least one major component permanently and legibly with all the information in 14 CFR § 45.15(b).

b. Also, mark the following permanently and legibly, with at least the manufacturer's name, subassembly part number, and the TSO number:

(1) Each component that is easily removable (without hand tools); and,

(2) Each subassembly of the article that you determined may be interchangeable.

c. If the article includes software and/or airborne electronic hardware, then the article part numbering scheme must identify the software and airborne electronic hardware configuration. The part numbering scheme can use separate, unique part numbers for software, hardware, and airborne electronic hardware.

d. You may use electronic part marking to identify software or airborne electronic hardware components by embedding the identification within the hardware component itself (using software) rather than marking it on the equipment nameplate. If electronic marking is used, it must be readily accessible without the use of special tools or equipment.

e. At least one major component must be permanently and legibly marked with the operational equipment class (for example, Class 2) as defined in RTCA/DO-229E, Section 1.4.2. Marking the equipment Class 4 indicates compliance to Delta Class 4 requirements. There is no requirement to mark the functional equipment class (for example, Gamma and Delta) defined in Section 1.4.1 of RTCA/DO-229E.

5. APPLICATION DATA REQUIREMENTS. You must give the FAA aircraft certification office (ACO) manager responsible for your facility a statement of conformance, as specified in 14 CFR § 21.603(a)(1) and one copy each of the following technical data to support your design and production approval. LODA applicants must submit the same data (excluding paragraph **5.l**) through their civil aviation authority.

a. A Manual(s) containing the following:

(1) Operating instructions and article limitations sufficient to describe the equipment's operational capability.

(2) A training package on using the equipment. This training package may be in any medium (video, software, and paper) and should familiarize an operator with all the functions and operation of the equipment.

(3) A quick reference guide with instructions on how to do (at least) the following:

- Enter a flight plan,
- Edit a flight plan,
- Execute a Direct-TO,
- Accomplish a holding pattern,
- Execute an approach procedure, and
- Execute a missed approach.

(4) Describe in detail any deviations.

(5) Installation procedures and limitations sufficient to ensure that the Stand-alone GPS/SBAS equipment, when installed according to the installation or operational procedures, still meets this TSO's requirements. Limitations must identify any unique aspects of the installation. The limitations must include a note with the following statement:

> "This article meets the minimum performance and quality control standards required by a technical standard order (TSO). Installation of this article requires separate approval."

(6) For each unique configuration of software and airborne electronic hardware, reference the following:

(a) Software part number including revision and design assurance level;

(b) Airborne electronic hardware part number including revision and design assurance level; and,

(c) Functional description.

(7) A summary of the test conditions used for environmental qualifications for each component of the article. For example, a form as described in RTCA/DO-160E, *Environmental Conditions and Test Procedures for Airborne Equipment*, Appendix A.

(8) Schematic drawings, wiring diagrams, and any other documentation necessary for installation of the stand-alone GPS/SBAS equipment.

(9) List of replaceable components, such as an antenna, by part number, that makes up the stand-alone GPS/SBAS equipment. Include vendor part number cross-references, when applicable.

(a) If the equipment can satisfy the requirements of RTCA/DO-229E only when used with a particular antenna, make the use of that antenna (by part number) a requirement on the installation. Include this requirement in the installation manual (IM) as a limitation.

(b) If the equipment is installed with a standard antenna, include maximum tolerable currents and voltages into the antenna port. See TSO-C144a, Passive Airborne Global Navigation Satellite System (GNSS) Antenna, applicable only to operational Class 1 equipment, or TSO-C190, Active Airborne Global Navigation Satellite System (GNSS) Antenna, applicable to all equipment operational classes.

b. Instructions covering periodic maintenance, calibration, and repair, to ensure that the stand-alone GPS/SBAS equipment continues to meet the TSO approved design. Include recommended inspection intervals and service life, as appropriate.

c. If not using a TSO-C205a Class Delta-4 functional sensor and the article includes software: a plan for software aspects of certification (PSAC), software configuration index, and software accomplishment summary.

d. If not using a TSO-C205a Class Delta-4 functional sensor and the article includes simple or complex custom airborne electronic hardware: a plan for hardware aspects of certification (PHAC), hardware verification plan, top-level drawing, and hardware accomplishment summary (or similar document, as applicable).

e. A drawing depicting how the article will be marked with the information required by paragraph **4** of this TSO.

f. A summary of the database updating process that meets the requirements in RTCA/DO-229E, Section 2.2.1.5.3. This summary must define the data quality requirements, identify the data source(s), and briefly describe the data distribution and update process.

g. A summary of the magnetic model updating process that meets the requirements in RTCA/DO-229E, section 2.2.1.3.12.

h. Adequate specifics on the interface between the GPS/SBAS sensor and other systems to ensure proper functioning of the integrated system. If the equipment depends on any external inputs (like baro-aided FDE) to satisfy the requirements of RTCA/DO-229E, make those inputs a requirement in the installation. Include this requirement in the IM as a limitation.

i. If the software qualification limits eligibility of the equipment to certain aircraft types, identify the qualification level, and that the equipment is not eligible for all aircraft types. For example, AC 23-1309-1(), *Equipment, Systems, and Installations in Part 23 Airplanes*, states that RTCA/DO-178B (or RTCA/DO-178C) Level C software may be associated with a *hazardous* failure condition for certain aircraft types. Identify other limitations applicable to the failure condition classification---for example, that two installed units are necessary.

j. If the equipment has not been demonstrated as compatible with satellite communications (SatCom) record in the limitations section that the equipment should not be installed in SatCom equipped aircraft.

k. Identify functionality or performance contained in the article not evaluated under paragraph **3** of this TSO (that is, non-TSO functions). Non-TSO functions are accepted in parallel with the TSO authorization. For those non-TSO functions to be accepted, you must declare these functions and include the following information with your TSO application:

(1) Description of the non-TSO function(s), such as performance specifications, failure condition classifications, software, hardware, and environmental qualification levels. Include a statement confirming that the non-TSO function(s) do not interfere with the article's compliance with the requirements of paragraph **3**.

(2) Installation procedures and limitations sufficient to ensure that the non-TSO function(s) meets the declared functions and performance specification(s) described in paragraph **5.k.(1)**.

(3) Instructions for continued performance applicable to the non-TSO function(s) described in paragraph **5.k.(1).**

(4) Interface requirements and applicable installation test procedures to ensure compliance with the performance data defined in paragraph **5.k.(1).**

(5) Test plans, analysis and results, as appropriate, to verify that performance of the hosting TSO article is not affected by the non-TSO function(s).

(6) Test plans, analysis and results, as appropriate, to verify the function and performance of the non-TSO function(s) as described in paragraph **5.k.(1).**

(7) Alternatively, identify non-TSO functionality or performance contained in the article not evaluated under paragraph **3** and submit previously accepted data for the non-TSO function for acceptance in parallel with this TSO application.

l. The quality system description required by 14 CFR § 21.608, including functional test specifications. The quality system should ensure that you will detect any change to the approved design that could adversely affect compliance with the TSO MPS, and reject the article accordingly. (Not required for LODA applicants.)

m. Material and process specifications list.

n. List of all drawings and processes (including revision level) that define the article's design.

o. Manufacturer's TSO qualification report showing results of testing accomplished according to paragraph **3.c** of this TSO.

6. MANUFACTURER DATA REQUIREMENTS. Besides the data given directly to the responsible ACO, have the following technical data available for review by the responsible ACO:

a. Functional qualification specifications for qualifying each production article to ensure compliance with this TSO.

b. Article calibration procedures.

c. Schematic drawings.

d. Wiring diagrams.

e. Material and process specifications.

f. The results of the environmental qualification tests conducted according to paragraph **3.d** of this TSO.

g. If not using TSO-C205a and the article includes software, the appropriate documentation defined in RTCA/DO-178B or RTCA/DO-178C specified in paragraph **3.e** of this TSO, including all data supporting the applicable objectives in RTCA/DO-178B or RTCA/DO-178C Annex A, *Process Objectives and Outputs by Software Level*.

h. If not using TSO-C205a and the article includes complex custom airborne electronic hardware, the appropriate hardware life cycle data in combination with design assurance level, as defined in RTCA/DO-254, Appendix A, Table A-l. For simple custom airborne electronic hardware, the following data: test cases or procedures, test results, test coverage analysis, tool assessment and qualification data, and configuration management records, including problem reports.

i. If not using TSO-C205a, all the data necessary to evaluate the geo stationary (GEO) satellite bias as defined in RTCA/DO-229E, Section 2.1.4.1.5.

j. If the article contains non-TSO function(s), you must also make available items **6.a** through **6.h** as they pertain to the non-TSO function(s).

7. FURNISHED DATA REQUIREMENTS.

a. If furnishing one or more articles manufactured under this TSO to one entity (such as an operator or repair station), provide one copy or on-line access to the data in paragraphs **5.a, 5.b** and **5.h** through **5.j** of this TSO. Add any other data needed for the proper installation, certification, use, or for continued compliance with the TSO, of the stand-alone GPS/SBAS equipment.

b. If the article contains declared non-TSO function(s), include one copy of the data in paragraphs **5.k.(1)** through **5.k.(4).**

8. HOW TO GET REFERENCED DOCUMENTS.

a. Order RTCA documents from RTCA Inc., 1150 18th Street NW, Suite 910, Washington, D.C. 20036. Telephone (202) 833-9339, fax (202) 833-9434. You can also order copies online at www.rtca.org .

b. Order copies of 14 CFR parts 21 and 45 from the Superintendent of Documents, Government Printing Office, P.O. Box 979050, St. Louis, MO 63197. Telephone (202) 512-1800, fax (202) 512-2250. You can also order copies online at www.gpo.gov.

c. You can find a current list of technical standard orders and advisory circulars on the FAA Internet website Regulatory and Guidance Library at http://rgl.faa.gov/. You will also find the TSO Index of Articles at the same site.

Susan J. M. Cabler
Acting Manager, Design, Manufacturing, &
Airworthiness Division
Aircraft Certification Service

APPENDIX 1. END-USE EQUIPMENT MANUFACTURER TESTS FOR DELTA CCA FUNCTIONAL SENSORS USED FOR NAVIGATION APPLICATIONS.

1. Scope.

This appendix describes the required supplementary equipment level testing, in addition to the environmental testing of RTCA/DO-229E, section 2.4, required by the end-use equipment manufacturer to receive a TSO-C146e Class Delta-4 authorization when using a TSO-C205a Delta CCA functional sensor. These test procedures are intended to streamline and simplify the TSO-C146e authorization process for the end-use equipment manufacturer by allowing credit for the design and selected testing done at the Delta CCA functional sensor level. However, the end-use equipment manufacturer retains full responsibility for the design and control of the article per their TSO-C146e TSOA.

2. General Principles.

(a) Testing methods for GPS/SBAS equipment have been standardized by RTCA/DO-229E and serve as the basis for TSO-C146e. RTCA/DO-229E was written with the perspective of equipment that can be installed on aircraft. Section 2.4 specifically addresses the issues of the environment in which the equipment operates and provides approved test methods to validate performance in this environment. Section 2.4 represents RTCA consensus in identifying which RTCA/DO-229E requirements are sensitive to environmental effects. These requirements are listed in the environmental tables referenced in section 2.4.1.

(b) The determination that a MOPS requirement is susceptible to the environment does not depend on whether or not the implementation is a CCA within some host equipment. This is the same concept as an equipment enclosure designed to protect against a benign environment compared to one designed for a severe environment; the identification of susceptible requirements is the same.

(c) Therefore this appendix uses the tables of RTCA/DO-229E, section 2.4.1 to identify the MOPS requirements susceptible to environmental conditions for a Delta CCA functional sensor in the end-use equipment. The focus is on the change in environment seen by the Delta CCA functional sensor as a result of its installation in the end-use equipment. For example, other components inside the end-use equipment may radiate RF energy that could interfere with the GPS functions; therefore the ambient testing done at CCA level is not equivalent to tests done in the end-use equipment. This is the basis for defining the RTCA/DO-229E, section 2.5 performance tests that need to be repeated by the end-use equipment manufacturer.

(d) The Class Delta-4 environmental table referenced in RTCA/DO-229E, section 2.4.1 are the prime source to determine the MOPS performance requirements susceptible to environmental conditions. Based on the table, Class Delta-4 has the same susceptible requirements as Class Beta, but adds two additional requirements for navigation display and database that are optional capabilities for Class Delta-4. Those Delta-4 requirements similar to Class Beta can be grouped in two categories: those susceptible to most types of environmental conditions (described in section 3) and those susceptible to just a few (described in section 4).

(e) The options for database and navigation displays in Delta-4 equipment do not present any repeat MOPS testing requirements for the end-use manufacturer incorporating a TSO-C205a Delta CCA functional sensor. The environmental qualification performed by the end-use manufacturer according to TSO-C146e is sufficient. The rationale is stated below.

(1) The database requirement testing under environment is meant to assure that the database storage hardware, which may be separate, is fully functional during environment. As the pass criteria for such testing is that the retrieved data is correct, the test procedures under environment are as sensitive to hardware issues as any ambient environment test. Therefore nothing justifies repeating tests under ambient conditions in the end-use equipment.

(2) End-use equipment that includes a database must perform the environmental qualification specified by TSO-C146e and MOPS section 2.4 irrespective of whether the database is hosted in the Delta CCA functional sensor or elsewhere in the equipment.

(3) It is impossible for the Delta CCA functional sensor to incorporate a display or be a display.

3. Performance Requirements Susceptible to Most Environmental Conditions.

The RTCA/DO-229E requirements for Accuracy (2.1.5.1) and Sensitivity and Dynamic Range (2.1.1.10) are sensitive to most environmental conditions. However, these requirements are linked to the message loss rate requirement in 2.1.1.3.2. Section 3.1 and 3.2 below identifies the testing end-use equipment manufacturers are required to repeat to demonstrate the Delta CCA functional sensor continues to meet the Accuracy, Dynamic Range, and Message Loss Rate performance requirements after installation in the end-use equipment. All tests will be run under conditions where the end-use equipment functions are fully enabled to create the worst-case environment.

3.1 RTCA/DO-229E, 2.5.8 Accuracy Test.

(a) The accuracy test described in section 2.5.8 is actually a joint test covering both accuracy and sensitivity and dynamic range. This joint testing also applies under environment as stated in section 2.4.1.1.5 with environmental adaptation as described in section 2.4.1.1.1.

(b) The demonstration of accuracy is done in accordance with section 2.5.8.1 only for the test case with a broadband external interference noise. This test must be repeated when the CCA is installed in the end-use equipment and it is sufficient to perform it using broadband interference.

(1) The environmental testing is limited to broadband interference as it represents the worst case signal to noise condition which is the most sensitive to environmental effects. This applies equally to the environment for the CCA created by the end-use equipment.

(2) Section 2.5.8 contains a measurement accuracy test in 2.5.8.1 with the detailed test procedure in 2.5.8.2. The 2.5.8.1 test must be run under the worst case environment identified in the "Additional considerations for internal interference sources" section below. The measurement accuracy testing can be combined with the message loss rate testing in 2.5.2.1.

(3) Section 2.5.8.3 is a 24-Hour actual satellite accuracy test. The section 2.5.8.3 test exposes the equipment to a variety of signal conditions and data processing conditions over varying satellite geometry that will increase confidence that no unforeseen interactions between components within the end-use equipment and the Delta CCA functional sensor goes undetected. The 24 hr testing in 2.5.8.3 can be combined with the 24 hr message loss rate testing in 2.5.2.4 (see Additional Considerations for Internal Interference Sources section).

(4) Section 2.5.8.4 (SBAS Tracking Bias) is an analysis of the GPS hardware and is therefore not necessary to repeat at the end-use equipment level as long as no extra RF components that affect the RF filtering response are inserted in the RF path. Otherwise the end-use equipment manufacturer must repeat the SBAS Tracking Bias test as well.

(c) The test threshold is relaxed from 110% to 125% as specified in table 2-25 of the 2.5.8.2.1 test procedure to shorten test time. However, Section 2.5.8 testing (excluding the SBAS Tracking Bias test in 2.5.8.4) for the CCA in the end-use equipment shall be under ambient conditions per section 2.5 with the 110% test pass threshold for maximum test sensitivity.

(d) The Section 2.5.8 testing (excluding the SBAS Tracking Bias test in 2.5.8.4) will be repeated against the accuracy requirement in section 2.1.5.1.

(e) Only the broadband external interference noise test case using minimum satellite power will be executed in most cases to shorten test time. Section 2.5.8.1 testing will be repeated for both minimum and maximum satellite power for the worst case environment only.

3.2 RTCA/DO-229E, 2.5.2 Message Loss Rate Test.

(a) Section 2.5.2 specifies the message loss rate test for the 2.1.1.3.2 message loss rate requirement. This test is conducted in conjunction with the 2.5.8 accuracy testing. Section 2.5.2.2 defines the test procedure to collect data verifying the SBAS message loss rate in the presence of interference using the test cases where the SBAS satellite is at minimum power. Section 2.5.2.3 defines the pass/fail criteria.

(b) The test in section 2.5.2.2 will be performed during the measurement accuracy broadband interference test case described in paragraph 3.1.

(c) The test procedure in section 2.5.2.4.1 is run in conjunction with the 2.5.8.3 24-hour accuracy test. Section 2.5.2.4.2 defines the pass/fail criteria for the test case described in paragraph 3.1(b)(3).

4. Performance Requirements Partially Susceptible to Environmental Conditions.

(a) The class Delta-4 table 2-20 in section 2.4.1 of RTCA/DO-229E indicates the requirements for Initial Acquisition Time (2.1.1.7) and Satellite Reacquisition Time (2.1.1.9) are sensitive to four environmental conditions: Icing, Lightning Induced Transient Susceptibility, Lightning Direct Effects, and Normal/Abnormal Operating Conditions. The requirements for Loss of Navigation (2.1.1.13.2, 2.1.5.12.2, and 2.3.6.2) are sensitive to low and high operating temperature.

> **Note:** Class Delta-4 provides deviation guidance only during the final approach segment of an LP/LPV approach where loss of integrity is treated as a loss of navigation capability.

(b) The Lightning Induced Transient Susceptibility, Lightning Direct Effects, or Icing environmental conditions are not pertinent to the environment created by the end-use equipment relative to the Delta CCA functional sensor. However, the end-use equipment manufacturer remains responsible for meeting the overall environmental qualification at the end-use equipment level.

(c) Loss of navigation indications are limited to temperature testing and the information in RTCA/DO-229E, sections 2.4.1.1.2 and 2.4.1.1.3 is appropriate. The purpose is to ensure that the interface used to indicate the loss of navigation is functional under environmental conditions after the Delta CCA functional sensor is installed in the end-use equipment. Sections 2.4.1.1.2 and 2.4.1.1.3 indicate that any source that generates the indication can be used since it is the interface and not the detection mechanism that is verified. The temperature testing done at the end-use equipment level is the worst-case scenario. It is not necessary to repeat the CCA level test at room temperature in the end-use equipment since the environmental qualification adequately addresses testing for these requirements.

Note: The Class Delta table requires more than just temperature testing under environment to support the optional display component of Class Delta. Since a CCA cannot be a display or incorporate a display, the additional testing under environment does not apply.

(d) RTCA/DO-160E section 16 relates to aircraft power supply (refer to TSO paragraph 3.g for environmental qualification requirements). Sections 16.5.1.2 and 16.6.1.2 are for supply voltage modulation (ac) /ripple (dc). Given the potential susceptibility of the Delta CCA functional sensor to power supply noise, it is prudent to repeat tests at the end-use equipment level on this basis.

(e) Sections 4.1 and 4.2 identify the testing end-use equipment manufacturers are required to repeat to demonstrate the Delta CCA functional sensor continues to meet the Acquisition Time and Reacquisition Time performance requirements relative to Normal/Abnormal Operating Conditions after installation in the end-use equipment. All tests will be run under conditions where the end-use equipment functions are fully enabled to create the worst-case environment.

4.1 2.5.4 Initial Acquisition Test Procedures.

The information in RTCA/DO-229E, section 2.4.1.1.4 on the initial acquisition test in section 2.5.4 applies. The end-use equipment manufacturer shall repeat the initial acquisition testing described in RTCA/DO-229E, section 2.5.4.

4.2 2.5.6 Satellite Reacquisition Time Test.

The end-use equipment manufacturer is required to repeat the Satellite Reacquisition Time testing in RTCA/DO-229E, section 2.5.6.

5. Additional Considerations for Internal Interference Sources.

(a) Installing a Delta CCA functional sensor into end-use equipment that also includes other functions requires careful evaluation of potential internal radiated and conducted interference. The end-use equipment manufacturer must evaluate each operating mode to determine if the mode changes the environment for the installed Delta CCA functional sensor. If there is only one environment or there is clearly one worst case environment, then the accuracy and message loss rate testing in section 3 can be run in that operating mode only. For example, if the end-use equipment includes an RF transmitter that radiates at one frequency; one could reasonably argue that setting the transmitter at full power with maximum data throughput will generate a clear worst-case environment in which to run all testing.

(b) In the case of multiple environments, the accuracy and message loss rate tests can either be run under each environment or the methodology in RTCA/DO-229E, section 2.4.1.2.3 can be used to run an aggregate with approximately equal time in each mode. The methodology in section 2.4.1.2.3 must be used to identify modes of greatest susceptibility under which the combined accuracy and message loss rate are repeated in addition to the aggregate test. For example, the 2.4.1.2.3 methodology is appropriate for end-use equipment that contains a high power transmitter operating on a large number of frequencies such that it is impractical to run a test at each frequency. This is analogous to the large number of frequencies that need to be tested during RTCA/DO-160E RF and Induced Signal Susceptibility testing and is the reason why the section 2.4.1.2.3 methodology was developed.

(c) It is sufficient to identify one worst case environment when performing acquisition and 24 hour accuracy testing.

6. Summary.

(a) The end-use equipment manufacturer that incorporates a Delta CCA functional sensor is required to repeat the following RTCA/DO-229E, section 2.5 testing under ambient conditions (see section 5) after installing the Delta CCA functional sensor in the end-use equipment:

- The section 2.5.8 Accuracy (excluding the SBAS Tracking Bias test in 2.5.8.4) adapted per section 2.4.1.1.1 except that the 110% test pass threshold is used.

  Note: Excluding the SBAS Tracking Bias test is acceptable, provided the end-use equipment does not insert in the RF signal path, components that affect the filtering response. Otherwise the end-use equipment manufacturer must repeat the SBAS Tracking Bias test as well.

- The section 2.5.2 Message Loss Rate Test.

- The section 2.5.4 Initial Acquisition Test.

- The section 2.5.6 Satellite Reacquisition Time Test.

(b) The end-use equipment manufacturer remains responsible for completing a full environmental qualification evaluation (see TSO paragraph 3.g) at the end-use equipment level. The end-use equipment manufacturer that incorporates a Delta CCA functional sensor is required to repeat Loss of Navigation indication and Loss of Integrity indication as part of the environmental qualification according to RTCA/DO-229E, sections 2.4.1.1.2 and 2.4.1.1.3.

APPENDIX 2. ADDITIONS TO RTCA/DO-229E.

This appendix describes required modifications and additions to RTCA/DO-229E for compliance with this TSO. This appendix adds a new section 1.8.3 on cybersecurity and GPS spoofing mitigation and additional required leg types in section 2.2.1.3 to RTCA/DO-229E.

The new section 1.8.3 contains no new requirements but provides information for cybersecurity and spoofing mitigation to make RTCA/DO-229E consistent with the new RTCA MOPS template and RTCA/DO-253D.

The new 2.2.1.3 leg type requirements are applicable to Class Gamma equipment only and are necessary to properly execute published instrument procedures designed to provide maximum efficiency, flexibility, and aircraft eligibility. These instrument procedure designs may include RNAV components and/or leg types associated with conventional procedures. The modifications and additions to section 2.2.1.3 are necessary to ensure Class Gamma equipment can properly execute current and future instrument procedure designs.

1.8.3 Cybersecurity and Spoofing Mitigation.

This section contains information to address intentional interference to the GPS. Spoofing is caused by RF waveforms that mimic true signals in some ways, but deny, degrade, disrupt, or deceive a receiver's operation when they are processed. Spoofing may be unintentional, such as effects from the signals of a GPS repeater, or may be intentional and even malicious. There are two classes of spoofing. Measurement spoofing introduces RF waveforms that cause the target receiver to produce incorrect measurements of time of arrival or frequency of arrival or their rates of change. Data spoofing introduces incorrect digital data to the target receiver for its use in processing of signals and the calculation of PNT. Either class of spoofing can cause a range of effects, from incorrect outputs of PNT to receiver malfunction. The onset of effects can be instantaneous or delayed, and the effects can continue even after the spoofing has ended. Improperly used or installed GNSS re-radiators act like spoofers. Re-radiators replay and GNSS emulator devices can present misleading information to GNSS equipment and/or could cause lasting effects.

Equipment manufacturers should implement measures to mitigate processing of erroneous data. Cross-checks of GNSS sensor data against independent position sources and/or other detection monitors using GNSS signal metrics or data checks can be implemented in the antenna, receiver, and/or through integration with other systems at the aircraft level. Data validity checks to recognize and reject measurement and data spoofing should be implemented in the receiver. Additional guidance and best practices related to GPS equipment can be found in the U.S. Department of Homeland Security document "Improving the Operation and Development of Global Positioning System

(GPS) Equipment Used by Critical Infrastructure"[1] and IS-GPS-200 Revision H, IRN003 28 July 2016. RTCA/DO-326A and ED-202A along with RTCA/DO-355 and ED-204 may also be useful to assess vulnerabilities and identify mitigations.

Aircraft equipment information vulnerabilities (such as cybersecurity risks) have been present for digital systems since the development of the personal computer (PC) in the late 70's and even longer for RF systems, and the advent of internet connectivity has substantially increased those risks. Typically, access to navigation receivers has been controlled such that they are considered vulnerable only through RF signals and OEM and/or aircraft operator controlled processes for maintenance and update. In some cases, aircraft GNSS receivers may be field loadable by approved personnel, requiring physical access and physical interface to the ground receivers. However, it is expected that not all aircraft in the future will rely on such physical isolation for the security of avionics. Internet and Wi-Fi connectivity have become popular as a means for aircraft or equipment manufacturers to update installed avionics software, to update databases, or provide an alternate means of communicating with the flight crew or cabin (e.g., in-flight entertainment, weather, etc.).

In most countries, the State provides oversight of safety-of-flight systems (sometimes referred to as "authorized services") which provide information to aircraft, such as ILS, VOR, GNSS, and DME, to name a few. However, the State typically does not provide oversight on "non-trusted"[2] connectivity such as the internet, Wi-Fi, or manufacturer-supplied equipment interfaces which permit input of externally-supplied data into aircraft systems. A manufacturer may expose aircraft information vulnerability through equipment design, or become vulnerable as a result of being connected to a common interface. Therefore, it is important that manufacturers consider aircraft information security risk mitigation strategies in their equipment design, particularly when the equipment is responsible for an interface between the aircraft and aircraft-external systems.

Apart from any specific aircraft-information-security-related performance requirements that are contained in the MOPS, it is recommended that manufacturers look at a layered approach to aircraft information security risk mitigation that includes both technical (e.g., software, signal filtering) and physical strategies. From a technical perspective, for example, this could include signal spoofing detection capabilities or more stringent, multi-factored authentication techniques such as passwords, PINs, and digital certificates. From a physical perspective, a manufacturer could consider connectors that require special tools to remove to prevent passenger tampering; although, navigation avionics are typically located in an avionics bay inaccessible to passengers. And finally, but just as

[1] https://ics-cert.us-cert.gov/sites/default/files/documents/Improving_the_Operation_and_Development_of_Global_Positioning_System_(GPS)_Equipment_Used_by_Critical_Infrastructure_S508C.pdf [Ed note: RTCA is investigating hosting this on their website]

[2] A "non-trusted" connectivity (sometimes referred to as third-party system) is any frequency or service where an Air Navigation Service Provider (ANSP) is not providing direct monitoring/protection.

important, manufacturers should consider supply chain risk management; for example, if a manufacturer is outsourcing software code development, is the contractor and its staff properly vetted?

Civil Aviation Authorities (CAAs) have a regulatory interest when an applicant's design makes use of a non-trusted connectivity where the installation can potentially introduce aircraft information security vulnerability. This requires the applicant to address not only the information security vulnerabilities and mitigation techniques for the new installation, but to also consider how vulnerability could propagate to existing downstream systems. Additionally, aircraft manufacturers should consider establishing appropriate procedures for aircraft operators to maintain security protection of the equipment during the life of the equipment installation in the aircraft. Therefore, it is recommended that manufacturers reference their equipment aircraft information security review and mitigation strategies so that the applicants can consider them, if necessary, in meeting the installation regulatory requirements.

2.2.1.3 Path Definition.

Replace the list of required leg types in the first paragraph after the last sentence as shown:

The desired path shall be defined according to the following leg types:

Leg Type	Description
IF	Initial Fix
CF	Course to Fix leg
DF	Direct to Fix leg
TF	Track to Fix leg
FA	Fix to Altitude leg
FM	Fix to Manual Termination
VA	Heading to Altitude leg
VI	Heading to Intercept
VM	Heading to Manual Termination
CA	Course to Altitude Leg

Holding legs

HA	Hold to Altitude
HF	Hold to Fix
HM	Hold for Clearance (manual termination)

Note 1: *There is no intent to require a heading or altitude source connected to the equipment to automatically execute leg types with heading or altitude components.*

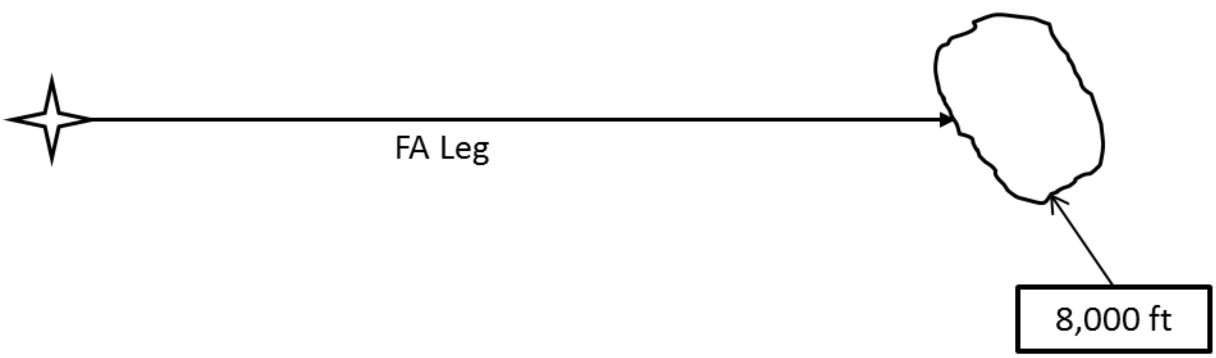
Manual equipment inputs for heading/altitude with manual aircraft control methods are acceptable for these leg types.

Note 2: *Cross-track deviation requirements are not applicable for VA, VI, and VM heading leg types*

Replace section 2.2.1.3.6 as shown and add the following leg type descriptions. Re-number existing paragraphs (starting with 2.2.1.3.7) to account for the newly added sections:

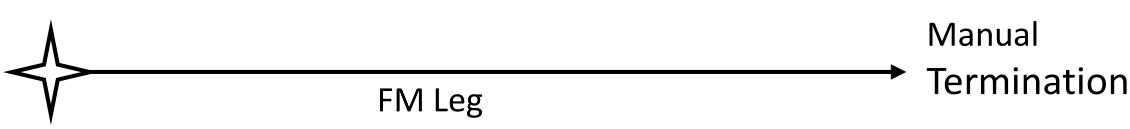
2.2.1.3.6 Fix to Altitude (FA).

An FA leg is defined by a geodesic path that starts at a fix, with a specified track at the fix and terminates at a point where the aircraft altitude is at or above a specified altitude. The outbound course from the fix, the fix, and the terminating altitude are provided by the navigation database. If the outbound course is defined as a magnetic course, the source of the magnetic variation needed to convert magnetic courses to true courses is detailed in section 2.2.1.3.12.



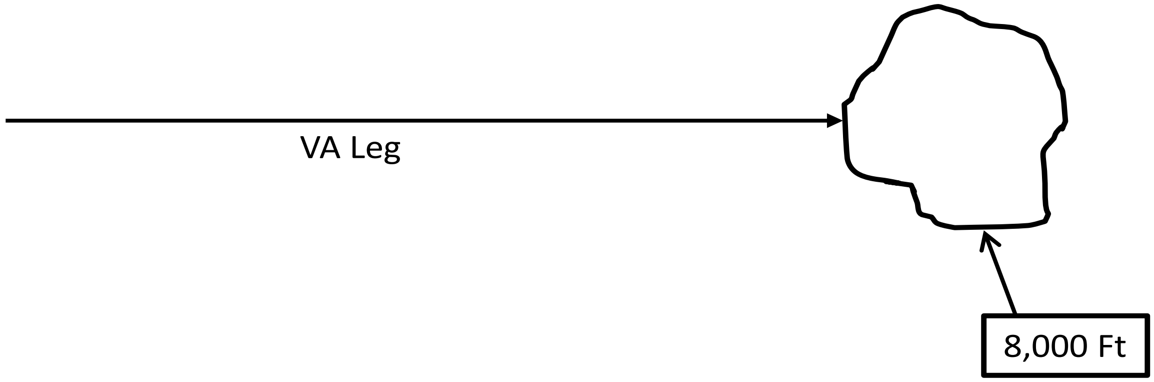
2.2.1.3.7 Fix to Manual Termination (FM).

An FM leg shall be defined as a specified track over the ground from a database fix until a manual termination of the leg. FM legs are similar to FA legs in terms of path construction except for manual termination versus terminating at an altitude.



2.2.1.3.8 Heading to Altitude (VA).

A VA leg shall be defined as a specified heading to a specific altitude termination at an unspecified position. No correction is made for wind.

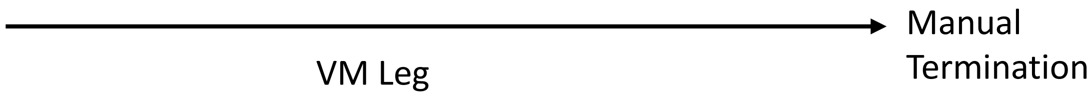


2.2.1.3.9 Heading to Intercept (VI).

A VI leg shall be defined as a specified heading to intercept a subsequent leg at an unspecified position. No correction is made for wind.

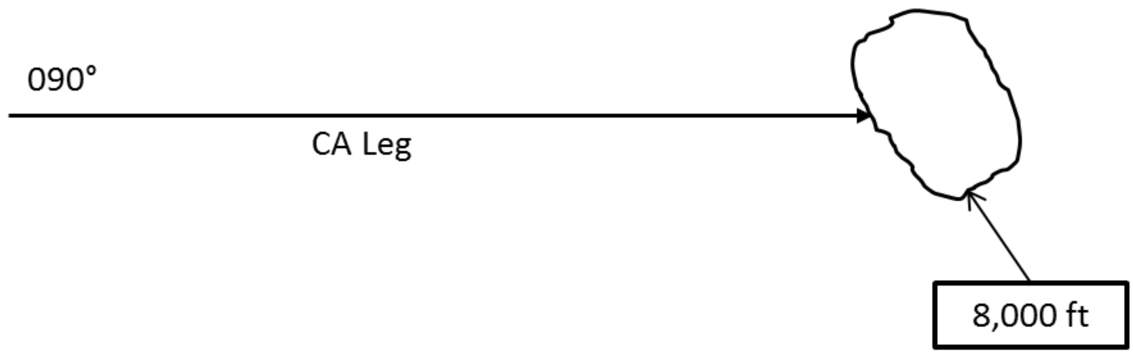
2.2.1.3.10 Heading to Manual Termination (VM).

A VM leg shall be defined as a specified heading until a manual termination of the leg. No correction is made for wind.



2.2.1.3.12 Course to Altitude (CA).

A CA leg shall be defined as a specified course to a specific altitude at an unspecified position. The course is flown making adjustment for wind.



2.2.1.3.13 Hold to Altitude (HA).

An HA leg is a holding pattern which terminates at the next crossing of the hold fix when the aircraft altitude is at or above the specified altitude. The altitude is provided by the navigation database. The source of the magnetic variation needed to convert magnetic courses to true courses is detailed in section 2.2.1.3.12.

2.2.1.3.14 Hold to Fix (HF).

An HF leg is a holding pattern which terminates at the first crossing of the hold fix after becoming established on the inbound course. This is typically after the entry procedure is performed. The source of the magnetic variation needed to convert magnetic courses to true courses is detailed in section 2.2.1.3.12.

2.2.1.3.14 Hold for Clearance (manual termination) (HM).

An HM leg is a holding pattern which terminates only after flight crew action. The source of the magnetic variation needed to convert magnetic courses to true courses is detailed in section 2.2.1.3.12.

Table 2-14 through Table 2-20.

The tables incorrectly reference and label RTCA/DO-160 sections 16.5.1.2 and 16.6.1.2 regarding “2.1.1.7 Acquisition Time” and “2.1.1.9 Reacquisition Time.” Change the table references as follows:

The MOPS Initial Acquisition Time requirement (2.1.1.7) applies to both AC and DC equipment under abnormal operating condition (DO-160E section 16.5.2 and 16.6.2) and the Satellite Reacquisition Time requirement (2.1.1.9) applies to both AC and DC equipment under normal operating condition (DO-160E section 16.5.1 and 16.6.1).

APPENDIX 3. OPTIONAL CHANGES TO RTCA/DO-229E ADDRESSING COMMON DEVIATION REQUESTS.

This appendix describes changes to RTCA/DO-229E based on deviations commonly granted in the past. Manufacturers have the option to use these changes to the specified sections in RTCA/DO-229E. Implementing these changes to RTCA/DO-229E should reduce the need for deviation requests.

2.2.1.1.4.5 Alphanumerics

Add a new next to last sentence to 2.2.1.1.4.5 and add the note:

Information critical to determining aircraft location and closure rate on the active waypoint, the waypoint name, and the desired track should be presented in a manner that facilitates rapid cross-checking by the pilot. This information should be differentiated from other information, and it should be located in a consistent manner (including order and position). The initial approach, final approach, missed approach and missed approach holding waypoints shall be labeled clearly when used as part of an approach procedure. An acceptable implementation is displaying the procedure-defined waypoint names. If space limitations require the use of abbreviations, see Section 2.2.1.1.7.

Note: There is no intent to require displaying both the procedure-defined waypoint name and whether the waypoint is the IAP, FAWP, MAP, or MAHWP.

2.2.1.1.4.8 Bearing Labels.

Change 2.2.1.1.4.8 and add the note:

All bearing-type data fields (bearings, courses, tracks, track angles, headings) shall have a descriptive abbreviation label of the field (for example, CRS for course) and all numeric values shall represent degrees relative to magnetic north. All bearing-type data fields (bearings, courses, tracks, track angles, headings) relative to true north shall be labeled as “T” to the right of the numeric value.

Note: Bearings, courses, tracks, track angles, headings are inherently understood to have numeric values in degrees relative to magnetic north. It is not necessary to label the numeric values with a degree symbol “°”or equivalent designation. However, it is necessary to distinguish when the numeric values are displayed relative to true north.

2.2.1.1.6 Set of Standard Function Labels.

Add the following note after Table 2-6:

Note: Acceptable alternatives to Table 2-6 are:

Enter (ENT) - Execute (EXE, EXEC), Select/Confirm (SEL/CONF).
- It is acceptable to use execute or confirm to differentiate from a prompt to enter data.

Flight Plan (FPL) - FPLN, Route (RTE)

Navigation Display (NAV, MAP) - ND, Flight Management System (FMS)

Suspend/un-suspend Automatic Waypoint Sequencing (SUSP) - Sequence Auto/Inhib

Direct-To (D→) - DIR

Vectors to Final (VTF) - Vectors, VECT

Loss of Integrity (LOI) on Final Approach Segment - NO APPR

Loss of Integrity (LOI) other than Final Approach Segment - NO RNP

Message (MSG, M) - Advisory, Alert

2.2.1.1.7 Set of Standard Abbreviations and Acronyms.

Change the second sentence in the paragraph as shown:

When using abbreviations and acronyms, the following abbreviations and acronyms should be used for the terms below, including use in checklists, messages, identification and labels for control functions. These abbreviations should not be used to represent a different term, and any abbreviations used shall be used consistently in the design of the pilot handbook supplements, quick reference checklists and the controls and displays of the equipment.

2.2.5 Class Gamma Requirements for LP and LPV Approach Operations.

Change 2.2.5 to make the existing note a paragraph and add the new note as shown:

The requirements in this section apply to LP and LPV approaches. This includes two approach types with vertical guidance: LPV (35m VAL) and LPV (50m VAL), and one approach type without vertical guidance: LP. These approach classifications are generically called "approach" in this MOPS. Except when specifically noted, every requirement applies to LPV (35m VAL) and LPV (50m VAL). Only the horizontal requirements apply to LP.

Note: It is acceptable for manufacturers to not implement LP approach capability in their equipment provided the equipment has an appropriate limitation and LP approaches are not available for selection by the pilot.

2.3 Class Delta-4 Requirements for Approach Operations.

Add the following note after the last paragraph in paragraph 2.3:

Note: It is acceptable for manufacturers to not implement LP approach capability in their equipment provided the equipment has an appropriate limitation and LP approaches are not available for selection by the pilot.